MODELING ACTIVITY DURATION AND TRAVEL TIME UNCERTAINTY ON DEPARTURE TIME CHOICE OF STUDENTS

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ABSTRACT

Activity timing and duration have attracted much attention under the research scope of activity-based approach. However, little attention has been given to the effects of uncertainties of these factors for activity scheduling. This paper focuses on the activity-travel modeling for the home-school-home (HSH) travels with considerations of both activity duration and travel time uncertainty. A departure time choice model is formulated. The model is calibrated with the data of Travel Characteristics Survey 2011 (TCS2011) in Hong Kong, to provide a better understanding of the travel behavior of HSH pattern. The result showed that longer travel time and larger travel time vibration of home-school travel resulted in student's earlier departure from school back home. The result also implied that students didn't prefer longer stay at school after school was over. Elder students had higher probability for longer stay at school compared to the younger students.
Keywords: students' travel behavior, activity duration uncertainty, travel time uncertainty, departure time modeling

1. INTRODUCTION

With fast development of urbanization, there is increasing need for developing advance transportation systems for travel demand analysis. The goal of travel behavior analysis has shifted from predicting single travel decisions to how trip sequences are generated in response to the changing of activity participation (Ettema et al., 1993). The traditional four-step trip-based models are criticized for theirs limitations under the increasing requirements for the understanding of the relationship between human activities and travel behaviors. In the past decades, activity-based approach has been recognized as a potential alternative to the traditional trip-based model. Activity-based approach treats that travels are derived from the human demand of participating various kind of social activities (Pas, 1985; Kitamura, 1988). The relationship between human activities and travels is considered under the activity-based approach. And the approach helps evaluating the performance of the transportation policy by analyzing the change of travelers' activity-travel behavior.

Early study on travel demand modeling in line of activity-based approach can be dated back to 1950s by Mitchell and Rapkin (1954). Hägerstraand set a benchmark study in early 1970s and described a time-space concept to model the activity-travel behavior. People participated their daily activities under a set of time-space constraints.

Random Utility Maximization (RUM) theory (McFadden et al., 1973) advanced a lot the studying the human's activity-travel behavior by providing a strong foundation of methodology theory. Consequently, a series of discrete choice models based on this theory had been developed for modeling the travelers' choice behavior. The benchmark framework of daily activity scheduling for travel demand analysis was developed in late 1990s (Ben-Akivai et al., 1996; Bowman, 1998; Bowman and Ben-Akiva, 2001). In their research, activity-travel scheduling was presented under a multi-level framework, consisted with several choice models (multinomial logit and nested logit models) on activity type, time of day departure, destination, mode, etc. In lower level model, the choice probabilities of the alternatives were conditional on the choice probabilities generated in higher level model. Such methodologies and ideas had been followed by quite a few researchers in line of studying activity-travel behavior problems using the activity-based approach.

Considering that uncertain environment does exist in both transportation networks and activities, McNally and Rindt (2007) pointed out that activity-based model should take into account the uncertain environment. Several papers (Bates et al., 2001; Noland and Small, 1995; Polak, 1987) had modeled the departure time choice problem and took travel time uncertainty into consideration. Ettema and Timmermans (2003) focused on daily activity-travel scheduling problem, incorporating timings and durations of activities for modeling the daily activity-travel patterns. Due to the data limited, constant travel time was used for calibration and left the issues of uncertainty for further study, e.g. travel time uncertainty. And uncertainty from the perspective of activities wasn't modeled in their later study (Ettema et al., 2004). Root and Recker (1981) detailed the concept of activity duration (uncertainty of level of service afforded by the activity destination). Recker et al. (1986) modeled the uncertainty of the predetermined travel plans as well as the interactions among the travel decisions. Later, A mathematical programming framework (Household Activity Pattern Problem (HAPP), Recker et al., 1995) was further developed in response to the limitations of 1986's model.

2. DATA DESCRIPTION

In our study, we used the data from the Travel Characteristic Survey (TCS) 2011 in Hong Kong for analysis and calibration. The survey is conducted every 10 years and the latest one was in 2011, which is used in our paper. The household interview survey covered a total of 35,401 households with 101,385 persons concerned. The sample size was approximately 1.5% among the 2,363,300 households (6,881,900 persons) in total in Hong Kong during the survey period. A total of 1,222,237 daily mechanized trips were recorded involved with 59,257 persons above 2 years old. A significant feature, i.e. the transit-oriented transportation system in Hong Kong, was summarized through the household interview trip survey. Up to round 88% of the daily travels were made by public transport modes, i.e. railways, bus, etc.

Home school based trips took up a proportion of 11% among the total trips. Younger children, i.e. kindergarten and primary students, their travel decisions were relied on their parents instead of making up the decisions themselves. As for the higher-level education students, i.e. university students, they enjoyed a large flexibility of school timetable for attending the classes. It's not easy to analyze their behaviors for studying the regular daily activity-travel pattern. Therefore, for representative, we analyzed the activity-travel patterns of students going to secondary schools, who were more reliable to make up their decisions for activity-travel behavior themselves. The proportion of secondary students among the whole population of students was showed in Table 1.

Table 1. Proportions of students with activity-travel records by study mode

Study level	Kindergarten	Primary	Secondary	University	Others	Total
Members with trip records	1011	2393	5047	1174	995	10620
Proportion	9.52%	22.53%	**47.52%**	11.05%	9.37%	100.00%

As seen from Table 1, among the students at different levels of study, secondary students took up the largest proportion, up to 47.52%. Further, among daily activity-travel patterns observed for secondary students, HSH activity-travel pattern was the dominant pattern with up to 84.57% of the students (secondary students, referred as students in the following paper for simplicity). In this paper, we focused on this activity-travel pattern with 4,267 observations.

Daily activity-travel pattern can be captured by the timings and durations of individuals' participation to different activities. Thus, departure time choice behavior of the students was modeled in this paper. As one out-of-home activity, i.e. school activity, was concerned with the home-school-home pattern, two decisions on departure time were required for determining this daily pattern. Thus, the departure times for home-school travel and school-home travel were analyzed. Some detailed characteristics of these two departure time patterns were shown in the Table 2 and Table 3. As seen, most of the observations were sampled during 06:00 a.m. to 08:00 a.m. and 15:00 p.m. to 19:00 p.m. for home-school travel and school-home travel, respectively. Therefore, for the construction of the departure choice set of home-school and school-home travel, two time windows, from 06:30 a.m. to 08:00 a.m. for home-school travel and from 15:00 p.m. to 19:00 p.m., were considered. In this way, we avoided generating some choice alternatives with too few samples. Due to the fact that nearly 90% of samples of the home-school travel were found falling in the hour from 07:00 a.m. to 08:00 a.m., the time interval for home-school departure time choice set was then set to be 30 minutes while one-hour interval was set for school-home travel. Detailed information and relevant independent variables can be referred in the Table 4. Apart from the independent variables listed in Table 4, one more variable was incorporated into the model. The variable was defined as the difference (absolute value, the same for reference in the rest of the paper) between the individual's school duration and the mean value of the samples within each choice alternative. A departure time choice model for school-home travel was formulated for calibration.

3. FORMULATION

3.1 Choice behavior

A discrete choice model was adopted in the paper for modeling the departure time choice model of school-home travel. The formulation followed the theory of RUM. A linear combination of independent variables was formulated as the utility for individual *n* choosing the departure time alternative *j* for school-home travel:

$$U_{n,j} = V_{n,j} + \varepsilon_j \tag{1}$$

$$V_{n,j} = \sum_{k=1}^{K} \beta_{T,k} \cdot T_{n,j}^{k} + \sum_{k=1}^{K} \beta_{STD,k}^{t} \cdot STD_{n,j}^{t,k} + \sum_{i=1}^{I} \beta_{D,i} \cdot D_{n,j,i} + \sum_{i=1}^{I} \beta_{STD,i}^{D} \cdot DD_{n,j,i} + \sum_{i=1}^{I} \beta_{DM,i} \cdot DM_{n,j,i} + \beta_n^X \cdot X_n \tag{2}$$

$U_{n,j}$ is the utility of individual *n* choosing the departure time choice alternative *j*. $V_{n,j}$ is the systematic utility of $U_{n,j}$. $T_{n,j}^{k}$ is the mean travel time of the k^{th} travel of alternative j chosen by individual n. $STD_{n,j}^{t,k}$ is the standard deviation of travel time for k^{th} travel of alternative j. $D_{n,j,i}$ is the mean duration of i^{th} activity of alternative j. $DD_{n,j,i}$ is the standard deviation of duration of i^{th} activity of alternative j. $DM_{n,j,i}$ is the difference between individual's school duration and the mean duration of each departure time alternative. X_n is the vector of the socio-economic variables of individual n. βs are the parameters of the independent variables, which are calibrated in this paper. ε is the random error for capturing the effects of unobserved factors. The unobserved random error ε is assumed to follow the Gumbel distribution. Thus, the probability for alternative *j* being choosing over the alternatives in the choice set is as Eq. (3):

$$P_{n,j} = \frac{exp\left(U_{n,j}\right)}{\sum_{j=1}^{J} exp\left(U_{n,j}\right)} \tag{3}$$

β is the number of the alternatives within the departure time choice set.

Table 2: Profile of departure time choice for home-school travel

Departure times	Sample size	Proportion
Earlier than 06:00	3	0.07%
06:00-06:59	406	9.51%
07:00-07:59	3746	**87.79%**
08:00-08:59	45	1.05%
09:00-09:59	24	0.56%
10:00-10:59	11	0.26%
11:00-11:59	6	0.14%
later than 12:00	26	0.61%

Table 3: Profile of departure time choice for school-home travel

Departure times	Sample size	Proportion
Before 12:00	14	0.33%
12:00-12:59	31	0.73%
13:00-13:59	37	0.87%
14:00-14:59	27	0.63%
15:00-15:59	1309	**30.68%**
16:00-16:59	2131	**49.94%**
17:00-17:59	318	7.45%
18:00-18:59	272	6.37%
19:00-19:59	79	1.85%
Later than 20:00	49	1.15%

Table 4: Choice set and independent variables (time and duration are measured in minutes)

H-S departure time	Alternative index	S-H departure time	Mean of H-S travel time	STD of H-S travel time	Mean S-H departure time	STD S-H departure time	Mean activity duration	STD of activity duration	Sample size
6:30-6:59	1	15:00-15:59	43.58	13.60	46.58	16.02	484.55	16.54	83
6:30-6:59	2	16:00-16:59	47.17	16.31	51.42	17.95	527.15	31.32	118
6:30-6:59	3	17:00-17:59	46.50	15.43	52.07	21.61	598.36	21.23	28
6:30-6:59	4	18:00-18:59	47.23	16.29	50.15	17.16	636.15	20.76	13
7:00-7:29	1	15:00-15:59	35.03	12.47	39.57	14.95	468.49	17.00	673
7:00-7:29	2	16:00-16:59	37.16	13.31	40.01	14.52	515.54	26.98	1145
7:00-7:29	3	17:00-17:59	39.79	12.61	40.09	13.95	578.83	17.54	146
7:00-7:29	4	18:00-18:59	34.45	11.87	37.09	14.14	628.04	19.87	129
7:30-7:59	1	15:00-15:59	25.78	9.20	32.21	14.12	451.43	16.56	493
7:30-7:59	2	16:00-16:59	27.71	10.47	31.23	12.83	496.92	26.27	758
7:30-7:59	3	17:00-17:59	26.97	10.12	32.11	13.27	566.47	16.27	117
7:30-7:59	4	18:00-18:59	26.55	9.96	30.86	9.10	604.75	20.43	95

3.2 Calibration method

Maximum likelihood estimation method was adopted for calibration in the paper. For the ease of calculation, the likelihood in Eq. (3) was transformed into log likelihood for estimation in Eq. (4):

$$max \quad logL = \sum_{n=1}^{N} log(P_{n,j}) \tag{4}$$

β s take the values that maximize the log likelihood in Eq. (4).

4. CALIBRATION RESULT AND DISCUSSION

The result of the calibration was shown in Table 5. The departure time choice alternative, 15:00 p.m. to 16:00 p.m., was treated as the based alternative.

Table 5. Estimated result

Variables	Estimated value	Std err	t-stat
T_{H-S}	$-$**0.25****	0.07	-3.47
STD_{H-S}	$-$**0.42****	0.16	-2.63
T_{S-H}	0.17**	0.08	2.23
STD_{S-H}	-	-	-
Duration (mean)	$-$**0.55****	0.08	-6.88
$STD_{duration}$	-	-	-
Difference from mean duration	$-$**0.08****	0.002	**-36.42**
Gender(16:00-17:00)	-	-	-
Gender(17:00-18:00)	-	-	-
Gender(18:00-19:00)	-	-	-
Income(16:00-17:00)	-	-	-
Income(17:00-18:00)	**0.92****	0.28	3.30
Income(18:00-19:00)	-	-	-
Car availability(16:00-17:00)	-	-	-
Car availability(17:00-18:00)	-	-	-
Car availability(18:00-19:00)	-	-	-
Age(16:00-17:00)	**0.23****	0.03	8.13
Age(17:00-18:00)	**0.24****	0.06	4.27
Age(18:00-19:00)	**0.35****	0.07	4.74
Initial log likelihood	-5265.15		
Final log likelihood	-1346.67		
Rho-squared (ρ^2)	0.7442		

** Significant at 0.05 level.

T_{H-S} : Mean travel time of home-school travel.

STD_{H-S} : Standard deviation of travel time of home-school travel. Similar description is for T_{S-H} , STD_{S-H} .

Mean duration (mean): mean value of the duration for school activity.

$STD_{duration}$: the standard deviation of the school duration.

Difference from mean duration: the difference between student's school duration and the mean value of duration in each S-H departure time alternative.

Age (16:00-17:00) : Alternative specific for socio-economic variable. Similar description is for Gender, Income and Car availability.

The results interpreted some implications for the activity-travel decisions for the choice of departure time for school-home travel. Negative influences of the mean and variation of travel time of the home-school travel in early morning were witnessed. As the target behavior modeled in the paper was the departure time choice behavior of school-home travel, the home-school travel time then can be viewed as the baseline of travel time between home and school, indicating the distance between school and home. The negative coefficient of home-school travel time meant that the longer travel time required from home to school, the earlier departure time choice would be preferred for school-home travel. It was reasonable that if longer time required on traveling, students would decide to leave earlier in order not arriving home too late. Those students with shorter travel time enjoyed more freedom to leave later when school was over.

The negative sign of the variation of travel time of home-school travel time indicated that students tended to schedule their timing for leaving earlier in response to the larger uncertainty, which might bring them higher risk of longer travel time. Positive influence of school-home travel was found. Such result might be criticized in a route choice problem. However, it got the evidence from McCafferty and Hall (1982). It was argued that it might be reasonable within the scope of departure time modeling. Regarding only departure times were modeled as choice alternatives, peak hours were definitely observed to be the most selected alternatives. More observations would be observed choosing peak hour regardless that the travel time was longer during the peak hour when compared to the off-peak hours. Thus, positive influence of mean travel time to the school-home choice behavior might not tell that students preferred longer travel time. It revealed the fact that though the travel time during peak hour was longer, students still scheduled their travel as school was over.

From the perspective of activity, the impact of activity duration to the departure time choice was investigated. The activity duration increased when postponing departure time from school. The negative coefficient for this variable implied that students were not willing to spend too much extra time in school if they were available to leave.

The most significant variable was the difference of individuals' school duration between the mean value of each departure time choice alternative. The negative sign meant that the larger the difference, the more unlikely that corresponding alternative was selected. It can be reasonable for understanding. Leaving early before the school was over was not permitted and was also treated as misbehavior. Thus, leaving too earlier might cause penalty to students. As for late departure, similar penalty did exit due to the fact that students were willing to go home as little benefit they would get for longer stay at school without the guidance from teachers. Therefore, such difference showed negative influence to the school-home choice behavior. Students preferred the alternative with smaller difference from mean value of duration.

Monthly household income had positive influence to the choice behavior on only one alternative. students in higher-income household tended to depart during 17:00 p.m. to 18:00 p.m. later than the peak hour from 16:00 p.m. to 17:00 p.m. The reason might be that their family could support them to attend some extra class beyond the normal teaching plan. In spite of this, students still unlikely to stay later than 18:00 p.m. at school. Those students with lower household income showed less passion for longer stay in school. Perhaps they were supposed to go back home for sharing responsibilities of household tasks.

The age of the students was the only significant personal socio-economic variables that was found to have significant influence to the school-home travels. This result reflected that elder students might face heavier pressure from studying. They needed to put more effort into the study and spent more time at school and thus departed a bit later when compared to younger students. This influence was seen monotonously increasing with the increasing of the age.

5. CONCLUSION AND FUTURE STUDIES

In this paper, an analysis had been carried out on the activity-travel behavior of home-school-home pattern. The departure times to and from school of secondary students were analyzed using the data of Travel Characteristic Survey 2011 in Hong Kong. A departure time model for school-home travel was proposed and calibrated.

The estimated result tells us several implications. (1) The travel time and its variation of home-school travel had negative influence on the departure time choice of school-home travel. The longer travel time leaded to earlier schedule of the departure so as to not arrive home late. In response to the large variation of travel time, students tended to add extra budget for the travel time and thus the earlier departure was preferred. (2) The impact of school-home travel time was found to be positive and its variation was not significant. It showed the students' preference of leaving school when school was over regardless of the potential longer travel time due to peak demand of school-home travel at that time. And this implication consisted with the negative influence of school duration. As the constraints for arriving home were not as strict as that for arriving at school, the variation of travel time showed less influence to the departure time choice than that of home-school travel. (3) The school duration uncertainty didn't show significant effects to the departure time choice behavior for school-home travel. The reason might be that duration staying at school was constrained by the school timetable and tended to be stable cross students. The insignificance of standard deviation of school duration might be the evidence to this factor. (4) There existed penalties for the students' school duration violated from the mean value of each departure time choice alternative. A negative effect of this factor on the departure time choice behavior was found be to be significant. The finding confirmed that the activity duration was an important factor on the decision of activity-travel behavior, especially for the fixed time schedule activity like school activity in the paper. (5) Only age and monthly household income were found to have significant impacts to the departure time choice. Elder students were found to leave school later. The students in the family with higher household income tended to stay a bit longer to attend some extra class after school was over.

Although this paper had uncovering some findings on the activity duration and travel time uncertainty under home-school-home activity-travel pattern, the work undertaken in this paper presented only a first step. Further research will follow to extend the research in a more comprehensive way:

(a) The paper mainly focused on home-school-home pattern under a departure time choice model. Single out-of-home activity was considered. Indeed, activities for different purposes should be studied such as some activities with relatively flexible time constraints, e.g. shopping or eating out-of-home activities. The impact of activity duration may provide more valuable implications for understand the activity-travel behavior.
(b) Although the impacts of some socio-economic factors had been investigated on the departure time choice behavior, variables like household size, the employment status of the students' parents, may also play significant roles in decision-making when scheduling the daily activity-travel.
(c) This paper adopted a linear function for the penalty for longer/shorter duration deviating from the mean value. In further studies, nonlinear function can be applied for evaluating such penalty.
(d) Household interactions should be incorporating for modeling the decision of activity-travel behavior as documented in varies papers (Hägerstraand, 1970; Pas, 1985; Kitamura, 1988; Kang and Recker, 2013), which affect the decisions of individuals' activity-travel behavior.

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